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ORIGINAL PAPER

Comparative field performance of some agricultural crops under a canopy of *Populus deltoides* and *Ulmus wallichiana*

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Abstract: The performance of maize, beans and sunflower was evaluated under a canopy of *Populus deltoides* and *Ulmus wallichiana* at Faculty of Agriculture, Wadura. The germination, growth and yield of the three test crops were suppressed under both tree species. The reduction, however, decreased when the cultivation of test crops was continued for three years. The inhibition potential generally is in the order of *P. deltoides* < *U. wallichiana* for maize and sunflower and *P. deltoides* > *U. wallichiana* for beans. Available soil N, P and K increased under the canopy of the selected tree species. The soils under *U. wallichiana* were more fertile than those under *P. deltoides*. Chromatographic investigation of extracts showed that the soils under *P. deltoides and U. wallichiana* differed in their composition of phenolic acids and phenolic glycocides. Except for caffic acid, all other allelochemicals disappeared and were no longer recovered in soil samples obtained after the second or third year of cultivation. Tree-crop compatibility can be explored in greater detail for improved management of traditional agro-ecosystems in Kashmir to increase the overall productivity of the land.

Keywords: allelopathy; agroforestry; phenolic acids; glycocides; growth performance; yield

Introduction

Agroforestry is a relatively young area of research. Crop productivity in agroforestry is governed by a number of complex factors, including allelopathy, that play a crucial role in determining the success of tree-crop associations (Inderjit and Weston 2001; Blanco 2007; Louis et al. 2007). Allelopathic interactions typically result from a combination of allelochemicals that interfere with several physiological processes in the recipient plant and influence microbial ecology and other physical, chemical and biological features that in turn affect nutrient mobilization in soil (Wu et al. 2001; Alford et al. 2007; Macias et al. 2007; Weih et al. 2008). Effects of any one of these abiotic or biotic constituents and other components of ecosystems can influence growth, distribution, productivity and survival of plant species (Cheng 1992; Inderjit and Dakshini 1999; Carlini and Grossi 2002). After entering soil, allelochemicals are generally degraded by microbes to less toxic forms (Cheng 1989). Thus, the allelochemicals in soils do not necessarily reflect the status of allelochemicals in the parent plant debris (Blum 1998). The fate of a chemical in the soil environment depends upon the interactions of many processes over time at a particular site under a set of existing natural conditions (Chau et al. 1981; Pistelli et al. 2002; Dixon et al. 2002; Popa et al. 2008; Qu and Wang 2008; Ignat et al. 2011). This emphasizes the significance of understanding the multifunctional aspects of allelopathy in structuring trophic levels, forming symbiotic relations and mediating competitive circumstances.

Allelopathic interactions include both inhibitory and stimulatory effects of allelochemicals released by plants. Increasing attention is paid to identification of plant based physiologically active compounds and their incorporation as components of various bio-preparations (Hoagland et al. 2008). The genera *Populus* and *Ulmus* are characterized by production of many allelochemicals, the type and abundance of which not only vary by species but also by the type of plant tissue. Boerjan et al. (2003) reported that Phenylpropanoids *viz.* ferulic acid, isoferulic acid, p-coumaric acid, are the dominant secondary metabolites in *Populus*. The investigation of bud exudates of different *Populus* species has led to the identification of different types of hydroxycinnamates and their derivatives (Ikonen et al. 2001; Peltonen et al. 2005). *Populus* also contains many species-specific classes of flavonoids and their derivatives (Harborne and Mabry

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1982; Harborne 2000). For instance, the bulk of the exudates of *P. balsamifera* and *P. trichocacpa* are characteristically composed of dihydrochalcones, whereas these compounds are essentially missing from bud exudates of *P. deltoides* and *P. nigra* (Greenaway et al. 1989). Similarly, the genus *Ulmus* possesses many species-specific secondary metabolites. Remarkably, *U. wallichiana* is an abundant source of flavonoid 6-*C*-glucosides. The chemical investigation of *Ulmus wallichiana* stem bark by Rawat et al (2009) resulted in isolation and identification of three compounds "(2S,3S)-(+)-3',4',5,7-tetrahydroxydihydroflavonol-6-C-β-D-gluc o pyranoside", "(2S,3S)-(+)-4',5,7- trihydroxy di hydro flavonol-6-C-β-Dglucopyranoside" and "3-C-β-D-glucopyranoside-2,4,6-trihydroxy methyl benzoate". Contrary to this, the extractives of *U. thomasii* contain "6-hydroxy-5,7-dimethoxy-2-napthoic acid", "6-hydroxy-3-hydroxymethyl -5,7-di-methoxy-2-napthoic acid lactone" and "2,6- dimethoxy-p-benzoquinone" (Chen and Hostetter 1969) All these allelochemicals are reported to be involved in metabolic activities of the recipient plants (Hostettler and Seikel 1969).

P. deltoides and *U. wallichiana* are extensively planted in Kashmir to serve various purposes. While *P. deltoides* is the main timber species for making veneers and packing cases, the wood of *U. wallichiana* is used for making high class carved doors and furniture. Both of these tree species are planted as windbreaks to mitigate the impact of winter storms. *U. wallichiana* is known in traditional Indian medicinal practice as a treatment for bone fracture (Jain 1991). The species provides excellent livestock fodder (Gaur 1999). Although the use of *P. deltoides* and *U. wallichiana* as perennial components of agroforestry systems was recommended by many studies, their compatibility with agricultural crops is yet to be worked out to take the full advantage of the space available under their canopies. Further, no work has been conducted on the qualitative presence of allelochemicals under the canopy of these tree species. With this in mind, the present study was undertaken with the main objective of evaluating compatibility of *U. wallichiana* and *P. deltoids* with maize, beans and sunflower. The other objective of our study was to determine the fate of identified allelochemicals following soil working and cultivation of crops over a period of three years. The study also aimed to describe changes in soil fertility that resulted from poplar and elm based agroforestry.

Materials and methods

Three experimental stands (11 to 13 years old) of *P. deltoides and U. wallichiana* located at the Faculty of Agriculture Wadura were used to evaluate the performance of selected agricultural crops grown under their canopies. The study site is situated between 34°17' N latitude and 74°33' E longitude at 1,590 m a.s.l. The seed sowing was done during first week of May in 10 m × 10 m plots laid under the canopy of each tree species planted at a distance of 3 m × 4 m. The experiment was replicated four times within the tree stands and suitable control plots of similar size were also laid outside the canopy in the open sunlight. The plots were irrigated once every week and all the cultural practices were carried out as per the recommended package of practices for these crops under the temperate conditions of Kashmir. Data were analyzed statistically as per the standard procedures prescribed by Gomez and Gomez (1984).

To quantify changes in soil fertility, soil samples were collected from ten randomly distributed places under the canopy of each tree species. The soil samples were passed through a 10-mesh sieve and immediately subjected to the analysis of chemical properties. Soil pH was determined electronically in 1:2.5 soil water suspension. The readings were taken directly on a Century digital portable kit (model ck 704) after appropriate calibration. The organic carbon content of soil was determined by Walkley and Blacks Chromic acid digestion and rapid titration method (Piper 1966). Available nitrogen, phosphorus and potassium were determined by alkaline permanganate method (Subbiah and Asija 1956), molybdate blue method (Vogel 1961) and thiozole yellow method (Young and Gill 1951), respectively.

The identification of allelopathic compounds was carried out using a paper chromatographic procedure modified by Kil (1992) from that of Lodhi and Rice (1971). For preparation of extracts about 500 g of soil was dispersed in 800 mL of distilled water for 1 h and the mixture was centrifuged at 4 × 103 rpm for 20 min. The wet soil was transferred to a conical flask. 300 mL of methanol was added to it and the contents were shaken for 48 h at 25°C. The mixture was again centrifuged at 4 × 103 rpm for 20 min. About 350 mL of acetone was then added and the mixture was shaken for 48 h at 25°C and again centrifuged at 4 × 103 rpm for 20 min. The mixture was filtered to discard the soil. The extract was evaporated to dryness in a rotary evaporator and residue was dissolved in 10 mL of acetone. Chromatograms were inspected under ultra violet light and compounds were marked.

Results

The performance of maize under two canopy types and in control plots is presented in Table 1 and Fig. 1. Germination of maize seeds was 10% lower under *U. wallichiana* and 5% lower under *P. deltoides* than in control plots. There was a concomitant decrease in plant height and dry weight, with inhibition of 3% and 6% under *P. deltoides* and *U. Wallichiana*, respectively. Compared to the control, flowering was delayed by eight days under *U. wallichiana* and six days under *P. deltoides*. The mean number of lines per cob was 11.7 under *U. wallichiana* and 13.4 under *P. deltoides* compared to 14.3 recorded in control plots. The number of seeds per cob was reduced by 14 and 10 percent under *U. wallichiana* and *P. deltoides*, respectively, as compared to 203 seeds/cob recorded in control plants. The differences in all parameters were statistically significant (p <0.05) for values recorded under both tree species and the control (Table 1).

The decrease in the test weight of seeds was 12% and 8% under the canopy of *U. wallichiana* and *P. deltoides*, respectively. The differences were statistically significant for values recorded both under the canopy of tree species and between tree species

and the control. Yield of maize was significantly reduced under the canopies of *U. wallichiana* (-18%) and *P. deltoides* (-9%) against the average yield of 4489.20 kg·ha^{-1} recorded in control plots (Fig. 1).

Germination, growth and yield of beans were also significantly reduced when sown under the canopies of selected tree species (Table 2 and Fig. 2). Germination was 8% and 4% lower under *P. deltoides* and *U. wallichiana*, respectively. Height of bean plants was 13% less under the canopy of *P. deltoides* and 5% less under *U. wallichiana*. Plant dry weights were 21% and 12% lower under *P. deltoides* and *U. wallichiana*, respectively. The initiation of flowering was delayed by three days under the canopy of *P. deltoides* and seven days under *U. wallichiana.* All these differences were significant (p <0.05) (Table 2).

The number of pods/plant was 11% fewer under *P. deltoides* and 6% fewer under *U. wallichiana*. The number of seeds per pod was 15% less under *U. wallichiana* than the 4.04 seeds per pod in control plots. The test weights of seeds were 6% and 3% lower under the canopy of *P. deltoides* and *U. wallichiana,* respectively. Total yield was 14% less in plants grown under the canopy of *P. deltoides* and 10% less under *U. wallichiana* than the average yield of 1,902.54 kg·ha^{-1} for control plots. The yield of beans was significantly less under tree canopies than in control plots (p <0.05).

Table 1. Performance of Maize under the canopy of *Populus deltoides* and *Ulmus wallichiana*

Parameters	Germination (%)	Plant height (cm)	Dry weight (g/plant)	Initiation of flowering	Lines per cob	Seeds per cob	Seed test weight (g/1000 seeds)	Yield (kg·ha^{-1})
Control	94.21(±1.55) (76.85)^{a}	172.39^{a}(±2.85)	283.17^{a}(±4.68)	47.33^{a}(±0.78)	14.33^{a} (±0.23)	203.32^{a}(±3.36)	208.76^{a}(±3.45)	4489.20^{a}(±74.22)
Populus deltoides	89.63(±1.15) (71.35)^{b}	166.87^{b}(±2.15)	264.70^{b}(±3.41)	53.33^{b}(±0.68)	13.43^{b}(±0.17)	183.55^{b}(±2.37)	191.29^{b}(±2.46)	4063.40^{b}(±52.46)
Ulmus wallichiana	84.66(±1.16) (67.01)^{c}	158.92^{c}(±2.18)	251.09^{c}(±3.44)	55.66^{c} (±0.76)	11.71^{c}(±0.16)	174.92^{c}(±2.40)	184.10^{c}(±2.52)	3692.55^{c}(±50.67)
C.D (p≤0.05)	3.27	4.92	7.94	1.51	0.39	5.62	5.81	123.7

Values in parenthesis for Germination are transformed values.

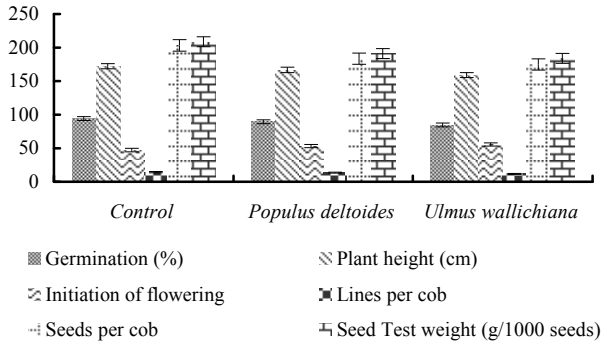

Fig. 1 Performance of Maize under the canopy of *Populus deltiodes* and *Ulmus waliichiana*

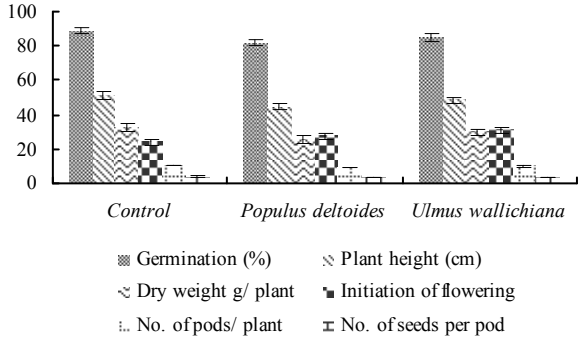

Fig. 2 Performance of Beans under the canopy of *Populus deltiodes* and Ulmus wallichiana.

Table 2. Performance of Beans under the canopy of *Populus deltoides* and *Ulmus wallichiana*

Parameters	Germination (%)	Plant height (cm)	Dry weight (g/plant)	Initiation of flowering	No. of pods per plant	No. of seeds per pod	Seed test weight (g/1000 seeds)	Yield (kg·ha^{-1})
Control	88.84 (±1.46) (70.68)^{a}	51.25^{a} (±0.84)	32.78^{a} (±0.54)	24.00^{a} (±0.39)	10.66^{a} (±0.17)	04.04^{a} (±0.06)	397.13^{a} (±6.56)	1902.54^{a} (±31.45)
Populus deltoides	81.94 (±1.05) (60.89)^{b}	44.71^{b} (±0.57)	25.67^{b} (±0.33)	27.33^{b} (±0.35)	09.53^{b} (±0.12)	03.19^{b} (±0.04)	373.42^{b} (±4.82)	1640.10^{b} (±21.17)
Ulmus wallichiana	85.13 (±1.16) (67.39)^{c}	48.65^{c} (±0.66)	29.80^{c} (±0.40)	31.00^{c} (±0.42)	09.98^{c} (±0.13)	03.42^{c} (±0.04)	386.23^{a} (±5.30)	1718.29^{c} (±23.58)
C.D (p≤0.05)	2.15	1.42	0.88	0.79	0.29	0.10	11.31	52.16

Values in parenthesis are transformed values

Compared to the control plots, germination of sunflower was 15% and 11% lower under the canopy of *U. wallichiana* and *P. deltoides*, respectively (Table 3 and Fig. 3). Plant heights were 25% and 14% lower for plants grown under *U. wallichiana* and

P. deltoids, respectively. Plant dry weights were 21% and 9% lower under the canopy of *U. wallichiana* and *P. deltoides*, respectively. The initiation of flowering was delayed by nine days under *U. wallichiana* and six days under *P. deltoides*. Means for all measured parameters were significantly lower (p <0.05) for crops grown under tree canopies than for control plots.

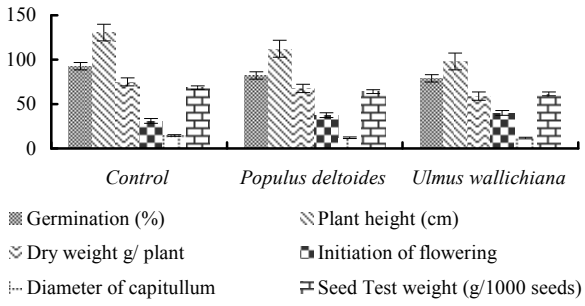

Fig. 3 Performance of Sunflower under the canopy of *Populus deltiodes* and *Ulmus wallichiana*

The diameters of sunflower capitula, the number of seeds per capitulum, the test weight of seeds, and total yield were also significantly lower under both tree canopies than in control plots (Table 3 and Fig. 3). Mean diameter of capitula was 20% less than in control plots under *U. wallichiana* and 17% less than in control plots under *P. deltoides*. Number of seeds per capitulum was 9% lower under *P. deltoides* and 13% lower under *U. wallichiana* than in control plots (Table 3).

The test weight of seeds was 10% and 7% less than in control plots under *U. wallichiana* and *P. deltoides*, respectively. The yield of sunflowers was significantly lower under both tree canopies. The average yield was 20% and 13% lower under *U. wallichiana* and *P. deltoides* than the mean of 9.69 q/ha under control.

The chromatographic investigation of extracts revealed that soils under *P. deltoides* and *U. wallichiana* were composed of four identical phenolic acids, *viz.* benzoic acid, caffic acid, salicylic acid and vanilic acid (Table 4). The two additional phenolic acids identified in the soils under *U. wallichiana* were p-hydroxybenzaldehyde and hydroquinone. Among the phenolic glycosides and aliphatic hydrocarbons, populin was identified in the soil samples collected under the canopy of *P. deltoides* and betulin was identified in samples collected under the canopy of *U. wallichiana.* Except for caffic acid, all other allelochemicals were no longer recovered in samples obtained after the second or third year of cultivation under the canopy of these two selected broadleaved species (Table 4).

Table 3. Performance of Sunflower under the canopy of *Populus deltoides* and *Ulmus wallichiana*

Parameters	Germination (%)	Plant height (cm)	Dry weight (g/plant)	Initiation of flowering	Diameter of capitulum	No. of seeds/ capitulum	Seed test weight (g/1000 seeds)	Yield (kg·ha^{-1})
Control	92.57 (±1.53) (74.63)^{a}	130.63^{a}(±2.16)	74.96^{a}(±1.24)	31.00^{a} (±0.51)	14.48^{a}(±0.23)	405.21^{a}(±6.69)	68.58^{a}(±1.13)	972.15^{a}(±16.07)
Populus deltoides	82.15 (±1.06) (65.05)^{b}	112.41^{b}(±1.45)	67.68^{b}(±0.87)	37.66^{b}(±0.48)	11.97^{b}(±0.15)	368.61^{b}(±4.75)	63.93^{b}(±0.82)	845.72^{b}(±10.91)
Ulmus wallichiana	78.98 (±1.08) (62.75)^{b}	97.92^{c}(±1.34)	58.93^{c}(±0.80)	40.00^{c}(±0.54)	11.61^{b}(±0.15)	350.53^{c}(±4.81)	61.41^{c}(±0.84)	777.67^{c}(±10.67)
C.D (p≤0.05)	2.67	3.53	2.05	1.05	0.38	11.23	1.92	26.41

Values in parenthesis are transformed values

Table 4. Allelopathic compounds in soil under the canopy of *Populus deltoides* and *Ulmus wallichiana* by paper chromatography during the study period.

Chemical component	*Populus deltoides*			*Ulmus wallichiana.*		
	1st year	2nd year	3rd year	1st year	2nd year	3rd year
Benzoic acid	+	+	-	+	+	-
Caffic acid	+	+	+	+	+	+
p-hydroxybenzaldehyde	-	-	-	+	+	-
Salicylic acid	+	-	-	+	-	-
Hyroquinone	-	-	-	+	+	-
Vanilic acid	+	-	-	+	-	-
Populin	+	+	-	-	-	-
Betulin	-	-	-	-	+	-

Notation: '+' present & '-' Absent

Data on soil reaction and changes in available nutrients under the canopies of *P. deltoides* and *U. wallichiana* are presented in Table 5. Availability of nutrients was greater under the canopy of both tree species. While soil pH increased from 6.20 to 6.90 under *P. deltoides* and 6.74 to 7.15 under *U. wallichiana*, organic carbon (OC) declined by 19% and 29%, respectively. Available

N increased by 6% and 19%, available P by 24% and 32% and available K by 8% and 19% under the canopy of *P. deltoides* and *U. wallichiana*, respectively. The most remarkable observation of our study was that the reduction in germination, growth and yield of all the test crops was less after the third year as compared to that recorded during the preceding two years of cultivation (Table 6).

Table 5. Soil reaction and status of available nutrients in soil under the canopy of selected tree species

Plant species	pH (1:2.5)			OC (%)			Available N (mg·kg^{-1})			Available P (mg·kg^{-1})			Available K (mg·kg^{-1})		
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	1st year	2nd year	3rd year	1st year	2nd year	3rd year	1st year	2nd year	3rd year
Populus deltoides	6.20 ±0.08	6.57 ±0.07	6.90 ±0.08	0.62 ±0.01	0.53 ±0.01	0.50 ±0.01	155.0 ±1.99	183.0 ±2.61	185.0 ±2.13	13.0 ±0.15	17.0 ±0.26	17.0 ±0.29	66.74 ±0.76	70.24 ±0.84	72.96 ±0.94
Ulmus wallichiana	6.74 ±0.09	6.90 ±0.12	7.15 ±0.10	0.69 ±0.01	0.60 ±0.01	0.49 ±0.01	160.0 ±1.87	190.0 ±2.14	198.0 ±2.28	15.0 ±0.23	18.0 ±0.28	22.0 ±0.25	72.80 ±0.84	88.71 ±1.92	90.40 ±1.44
Control (Fallow lands)	6.97 ±0.14	7.12 ±0.13	7.17 ±0.09	0.51 ±0.01	0.50 ±0.01	0.48 ±0.01	107.0 ±1.23	108.9 ±1.36	106.7 ±1.33	9.0 ±0.10	12.0 ±0.18	11.0 ±0.14	44.18 ±0.66	47.07 ±0.53	48.12 ±0.59

Table 6. Performance of maize, sunflower and bean under the canopy of *Populus deltoides* and *Ulmus wallichiana*

Maize

Plant species		Germination (%)	Plant height (cm)	Dry weight (g/plant)	Initiation of flowering (days)	No. of lines per cob	No. of seeds per cob	Seed test weight (g/1000 seeds)	Yield (kg·ha^{-1})
Control	1st year	90.96	181.69	268.85	46	14.22	202.9	190.27	4396.68
	2nd year	93.66	174.5	281.42	47	14	204	214.5	4575.85
	3rd year	95.33	178.5	296.37	49	14.5	200.5	219.37	4483.92
Populus deltoides	1st year	83.19	167.53	246.68	52	12.99	158.37	177.24	3878.62
	2nd year	90.66	163.6	262.96	54	12.8	188	191.95	4080.17
	3rd year	94	168.4	282.26	54	14.1	187	202.07	4216.36
Ulmus wallichiana	1st year	75.86	154.48	229.15	54	9.9	151.17	174.54	3396.3
	2nd year	84.66	158.4	254.26	56	11.4	176	182.78	3737.54
	3rd year	92.33	162.4	268.19	57	12.8	180.3	193.27	3945.19

Beans

Plant species		Germination (%)	Plant height (cm)	Dry weight (g/plant)	Initiation of flowering (days)	No. of lines per cob	No. of seeds per cob	Seed test weight (g/1000 seeds)	Yield (kg·ha^{-1})
Control	1st year	82.36	46	27.47	23	11.1	3.79	389.61	1845.49
	2nd year	90.33	52.2	33.64	25	10	4.2	368.54	1896.47
	3rd year	62.66	54.3	35.26	24	10.5	4	430.29	1956.67
Populus deltoides	1st year	73.67	33.82	20.79	26	9.17	2.76	365.3	1511.28
	2nd year	83.66	45.9	26.84	27	9.33	3.33	344.65	1650.24
	3rd year	87	49.2	29.03	29	9.9	3.4	407.64	1752.76
Ulmus wallichiana	1st year	76.18	38.3	24.52	29	9.95	2.88	376.09	1609.8
	2nd year	88	49.5	29.45	32	9.66	3.66	359.92	1729.52
	3rd year	90.66	51.7	31.85	32	10.2	3.6	420.56	1809.21

Sunflower

Plant species		Germination (%)	Plant height (cm)	Dry weight g/plant	Initiation of flowering (days)	No of lines per cob	No of seeds per cob	Seed test weight (g/1000 seeds)	Yield (kg/ha)
Control	1st year	88.62	125.33	69.06	32	13.68	426.39	60.76	945.49
	2nd year	95	135.3	79.42	31	14.8	401.94	69.89	969.37
	3rd year	93	129.4	76.07	30	14.7	384.5	74.19	998.29
Populus deltoides	1st year	80.05	96	56.89	36	10.13	367.68	54.51	796.66
	2nd year	81.66	122	73.51	38	12.6	374.62	66.04	839.85
	3rd year	84	118.6	71.16	39	12.9	362.3	70.58	897.58
Ulmus wallichiana	1st year	77.89	80.58	45.27	38	9.93	346.19	50.98	702.38
	2nd year	78.33	105.6	65.86	40	12.1	352.1	64.27	770.54
	3rd year	80.33	107.3	65.37	42	12.5	350.9	68.15	856.79

Discussion

Agroforestry is a multispecies land use system which involves integration of tree crops with agricultural crops and/or livestock in some form of spatial arrangement or temporal sequence. Because tree species co-exist with the agricultural crops, their allelopathic compatibility may be crucial to the success of an agroforestry system (Hepperly et al. 1992). Allelopathy involves the addition of some toxic substances into the habitat that may render it favourable or unfavourable for other crops or organisms growing in the vicinity (Chen and Hostetter 1969; Rawat et al. 2009). Our study shows that germination, growth and yield of all three test crops were significantly reduced when grown under canopies of *P. deltoides* or *U. wallichiana*. The reduced growth and production of the test crops might be attributed to the presence of toxic secondary metabolites, *viz.* benzoic acid, caffic acid, salicylic acid, vanilic acid, p-hydroxybenzaldehyde and hydroquinone under the tree canopies. All these allelochemicals inhibit plant growth by affecting the division, elongation and ultra-structure of cells or by altering mineral uptake, chlorophyll content and enzyme activity (Horsley 1976; Tseng et al. 2003). Reduced crop growth and yield were reported to occur beyond tolerable economic levels when allelochemicals accumulated to physiologically active levels in soils (Boerjan et al. 2003; Hussain et al. 2004; Startsev et al. 2008). The results indicate a selective influence of canopy species on the growth and development of maize. Although the yields of all our test crops were lower when grown under tree canopies, the deficits were only 9% and 13% for maize and sunflower when grown under *P. deltoides* and 10% for beans cultivated under *U. wallichiana*. This suggests that maize and sunflower are more compatible with *P. deltoides* while beans are better suited to *U. wallichaina*. This variation in relative performance of test crops is evidently related to selective allelopathic potential of the canopy species as reported by Kruse et al. 2000 for *A. oligantha* and Rizvi et al. 1999 for Sorghum.

The microhabitat under the canopies of both tree species proved to be more hostile for sunflower as compared to maize and beans. Jilani et al. (2008) reported that in order to hamper plant growth, allelochemicals must accumulate in the rhizophere and persist for long time periods at phytotoxic levels. However, after their entry into the environment, persistence, availability and biological activities of allelochemicals are influenced by various factors including soil microbes which transform them into compounds with modified biological properties. Such bio-transformations directly affect the overall allelopathic capability of the producer plant. Our results confirm the findings of Blum (1998) that soil working followed by cultivation of crops under a canopy of trees can improve the microhabitat conditions for soil microbes that consume allelochemicals as carbon sources, thus reducing their bio-availability and/or degrading their toxicity. Chou et al. (1981) found that the level of phyto-toxicity is dependent on the degradation of allelochemicals in the soil. Goss (1973) and Wang et al. (1978) reported that allelochemicals in plants occur as glucocide bonds which are broken by enzymatic or microbial action that renders them less harmful. These results corroborate findings of studies of crops exposed directly to aqueous extracts from leaves and roots of selected trees wherein the inhibition potential of the extracts increased with increasing age of the donor plants. These results suggest that laboratory bio-assay of allelochemicals does not enable accurate prediction of their effects under field conditions where allelopathy cannot be singled out as the only prominent factor affecting the characteristics of companion crops (Rice 1984). These allelopathic interactions can thus be explored more precisely for improved management of traditional agro-ecosystems to increase the overall productivity of the land.

The results on improvement in soil characteristics indicate that soils developing under *U. wallichiana* were more fertile and had 6.5%, 22.7% and 19.3% more available N, P and K content compared to soils developing under *P. deltoides*. This variation in soil fertility status under the selected tree species might be explained by differences in litter properties as reported by Sharma (1992) and Singh et al. (1993). In Tlaxcala, Mexico available N, P and K were 1.5, 4, and 3 times greater, respectively, under a canopy of *Primus capuli* trees intercropped with maize (Altieri et al, 1987). Wang et al. (2005) showed that changes in particulate organic matter (POM) occurred over shorter time periods after the establishment of agroforestry systems. Josre (2009) and Nair et al. (2009) found that compared with monocropping systems, trees in agroforestry systems can enhance soil organic matter levels by adding a substantial quantities of organic carbon inputs which, in turn, rejuvenate soil fertility upon decomposition. The present study showed that while soil organic carbon content declined, soil pH and available N, P and K increased over a period of three years under the canopies of both tree species. These results are in conformity with those reported by MeClaugherty et al. (1982), who found that working soil for crop cultivation under the canopy of trees breaks down fine root networks and adds nutrients to the soil. Mohsin et al. (2000) and Sharma et al. (2000) concluded that litter fall and fine roots are important for maintaining soil fertility in agroforestry systems.

Conclusions

In conclusion, the land use change from monocropping to poplar and elm based agroforestry systems influenced soil reaction and increased soil fertility with respect to availability of nutrients.Poplar and elm are multipurpose agroforestry tree species and occupy an important position in the rural economy of Kashmir. The information generated from this study thus offers direct benefits to local farmers who manage poplar and elm based agroforestry systems. Our study also adds to the knowledge of the fates of allelochemicals following cultivation of crops under tree canopies. The allelochemical activities in soils are limited in time and space. Time limitation occurs because degradation processes instigated by soil working and cultivation reduce the availability of allelochemicals in the soil solution.

Space limitation occurs because the effect of these naturally occurring chemicals would be spatially limited to plants near the donor plant owing to the reduced concentration following soil working. Despite these revelations, there is great need for strengthening research to determine biological, chemical and environmental inter-relationships of allelochemicals within the system to explore the full advantages of any poplar and elm based agroforestry model.

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